WATER RESOURCES ANALYSES

FLOW CATEGORY ANALYSIS
for flow duration curves

Eric Smirnow
U.S. Forest Service
Delta, Co 81416

REGION 2

FLOW CATEGORY ANALYSIS

A METHOD TO FACILITATE DEVELOPMENT OF FLOW DURATION DATA
ESPECIALLY FOR STREAMS HAVING UNSTABLE CHANNELS AND/OR CONSIDERABLE
DAILY RANGE IN STAGE DURING SPRING RUNOFF

ERIC SMIRNOW
HYDROLOGIC TECHNICIAN

GRAND MESA, UNCOMPAHGRE, & GUNNISON NF
2250 HIGHWAY 50 SOUTH
DELTA, COLORADO 81416

(303) 874-7691

1987

FLOW CATEGORY ANALYSIS

A METHOD TO FACILITATE DEVELOPMENT OF FLOW DURATION DATA ESPECIALLY FOR STREAMS HAVING UNSTABLE CHANNELS AND/OR CONSIDERABLE DAILY RANGE IN STAGE DURING SPRING RUNOFF

Flow duration analysis is a vital quantitative tool for sediment transport/yield studies, channel maintenance investigations, instream flow determinations, water augmentation surveys, flushing flow studies, and water resource management. Other uses for this method include such applications as rainfall intensity studies from recording precipitation gage charts, when accelerated time scales and fine point felt-tip pens are used to provide superior quality graphic record.

Snowmelt dominated streams, particularly those also having unstable channel materials, pose unique and difficult problems for persons engaged in the quantification of water resources, sedimentation, fluvial geomorphology, etc. The following method has been devised to simplify and expedite some of the tedious, time consuming, and possibly inaccurate tasks involved in reducing raw hydrographical data into meaningful summarized formats.

The following methodology requires adherence to well known techniques in hydrography using standard field equipment and computational methods (selected technical manuals have been listed in the bibliography). Utilizing specialized forms commonly used by the U.S. Geological Survey, Water Resources Division, which are especially designed for data collection/manipulation/collation in water resources investigations will substantially aid the investigator in his/her work.

FLOW CATEGORY ANALYSIS: The procedure involves the summation of discrete and consistent intervals of time for preselected ranges in stage, which correspond to groups of time in which streamflow equals or exceeds some relatively small increment in discharge. The mylar template method works well for any type of stage recorder, provided that a graphic, not digital (punch tape), record of water surface level fluctuations is produced. Numeric/digital flow data can also be converted to flow categories, provided there are enough values (such as hourly gage heights from telemetry gaging stations, or tapes from punch stage recorders). Computer programming will probably be necessary in this case.

METHODOLOGY (GRAPHIC DISCHARGE RECORD):

1) Using strip charts from a stage recorder plus the applicable rating table (exhibits 1, 1-A; 2, 2-A), develop a clear mylar template (examine samples in envelope) that will "fit" the charts used by the recorder. Each template represents the stage/discharge relationship for specific flow categories given

a particular rating curve and rating table. A shift correction can be built into the template for each rating that will accomodate any actual or anticipated positive or negative shifts that must be applied to the gage height record due to changes in channel conditions at the gage.

2) Determine the total range in stage and corresponding discharges for the entire period to be analyzed, and then subdivide the range of discharge values into a convenient number (such as between 20-30) of flow categories. The categories will encompass a range of discharge; data can be manipulated using the min/max values of the range, or the mean (exhibits 3 and 5).

3) Select a time interval to be used when tallying the flow categories from the charts. Choice of time interval will depend on such variables as the flow characteristics of the stream, climate, the accuracy of the graphical record, the desired accuracy of the resulting flow duration data, etc. An intermittent stream subject to infrequent, but occasionally abrupt rainstorm events might warrant an hourly interval. Snowmelt dominated mountain streams which have large diurnal fluctuations during runoff, but relatively constant low flows the balance of the year, might be analyzed adequately with a 3 hour time interval (such as the sample stream in this paper). ONCE A TIME INTERVAL IS SELECTED, IT MUST REMAIN CONSTANT FOR THE ENTIRE STUDY.

4) Place the template on the strip chart (exhibit 2), and tally the number of flow categories for the selected time interval (exhibits 3-1 through 3-4; 3-A). Since snowmelt dominated streams will usually have a relatively uniform (low) discharge the balance of the year, the tallying process can easily be done in a brief period of time.

This scheme creates a large population of events for streams that may have widely varying sediment transport capability (as well as actual concentrations) during a single 24-hour period during runoff. Commonly, small snowmelt runoff dominated streams have insignificant inorganic sediment transport, except for possible summertime thunderstorm events, the remainder of the year. Attempting to accurately define sediment transport regimes for streams having an excess of energy in the springtime, but which are placid the balance of the year by using mean daily discharge values is notoriously inaccurate.

SEDIMENT TRANSPORT AND FLOW DURATION ANALYSIS - A PRACTICAL EXAMPLE: On snowmelt dominated mountain streams such as Cottonwood Creek near Pinon, Colorado, much of the suspended solids and practically all the bedload material are moved during spring runoff, a fraction of the time in a year. To further complicate matters, fairly soft sandstone from the Dakota formation in the headwaters of the stream lines a highly erodable Mancos Shale derived soil downslope. The result, an "armored" channel type, can easily shift bed material of impressive particle size, as well as the water surface elevation at almost any point along the stream's lower reaches. These shifts occur often, either positively or negatively during the height of the runoff period. When

the stream has enough energy to saltate platy/oblate or rectangular sandstone rocks in the 4" to 10" size class along the streambed, this phenomenon occurs practically on a daily basis, particularly at night during diurnal peaks. The result substantially complicates streamflow data reduction and interpretation, due to varying daily shift corrections, abruptly changing stage/discharge relationships, days which should be subdivided rather than averaged for a mean daily gage height/discharge, and so on. Furthermore, since suspended sediment and bedload are usually power functions (simple or complex) of discharge, the need for some type of subdivision during periods of high stream energy becomes all the more crucial to develop numerically reliable sediment yields.

For this particular watercourse, upstream conditions such as active beaver ponds, cut and sloughing raw banks, etc., further complicate widely varying sediment concentrations for given discharges.

Values of actual data (exhibit 4) obtained from a project gaging station site on the Uncompahgre National Forest, Colorado, are included in this paper as an example of possible uses for flow category analysis. Measurements and samples were collected and analyzed by the author. All data is preliminary, and subject to revision (exhibits 5 and 6).

CONCLUSIONS: Flow category analysis is designed to provide investigators in water resources with a tool that will expedite and refine the generation of flow duration curves/tables, flow regime frequencies, sediment yields, and so on. The method can be modified for use in other investigations, such as rainfall intensity studies. By expanding numerical data into a larger population of discrete events, rather than using mean values over longer periods of time, superior accuracy of data can be obtained, as well as saving the investigator a substantial amount of time and effort in data reduction.

PROCEDURAL FLOW CHART FOR FLOW CATEGORY ANALYSIS

Obtain Copy of USGS
Strip Chart(s) & Applicable
Rating Table(s)

Construct Gaging Station
With Continuous Stage Recorder

Measure Discharge At
Varying Stages

Develop Stage/Discharge Relationship

Obtain Other Data/Parameters
If Necessary

Obtain & Analyze Samples If
Necessary

Develop Sediment,
TDS, Other Rating
Curves & Equations

Make Mylar Template of Flow
Categories For Each Rating

Determine Discreet Time
Interval To Be Used For
Flow Duration Analysis

Use Charts From
Stage Recorder

Tally Total # of Time
Periods

Tally # of Events in
Each Flow Category

Develop Flow Duration Curve/Table

Determine Channel
Maintenance Flows,
Augmentation Increases,
Flushing Flows, Etc.

Determine Sediment, TDS, Misc.
Yields From Sample Analysis &
Applicable Ratings

REFERENCES

Buchanan, Thomas J., & Somers, William P.; STAGE MEASUREMENT AT GAGING STATIONS; Techniques of Water Resources Investigations of the U.S. Geological Survey; Book 3, Chapter A7; 1982.

Buchanan, Thomas J., & Somers, William P.; DISCHARGE MEASUREMENTS AT GAGING STATIONS; Ibid.; Book 3, Chapter A8; 1980.

Carter, R.W., & Davidian, Jacob; GENERAL PROCEDURE FOR GAGING STREAMS; Ibid.; Book 3, Chapter A6, 1968.

Kennedy, E.J.; COMPUTATION OF CONTINUOUS RECORDS OF STREAMFLOW; Ibid.; Book 3 Chapter A13; 1983.

Rantz S.E., et al.; MEASUREMENT AND COMPUTATION OF STREAMFLOW: VOLUME 1., MEASUREMENT OF STAGE AND DISCHARGE, and VOLUME 2., COMPUTATION OF DISCHARGE; U.S. Geological Survey Water-Supply Paper 2175, 1983.

Thomas, Robert B.; CALIBRATING SALT: A SAMPLING SCHEME TO IMPROVE ESTIMATES OF SUSPENDED SEDIMENT YIELD; unpublished paper; USDA Forest Service, Pacific Southwest Forest & Range Experiment Station, 1700 Bayview Street, Arcata, CA 95521; pp.1-20; 1985.

ERRORS IN ESTIMATING SUSPENDED SEDIMENT; Proceedings of the D.B. Simons Symposium of Erosion and Sedimentation; Fort Collins, CO; pp. 1.162-1.177; 1983.

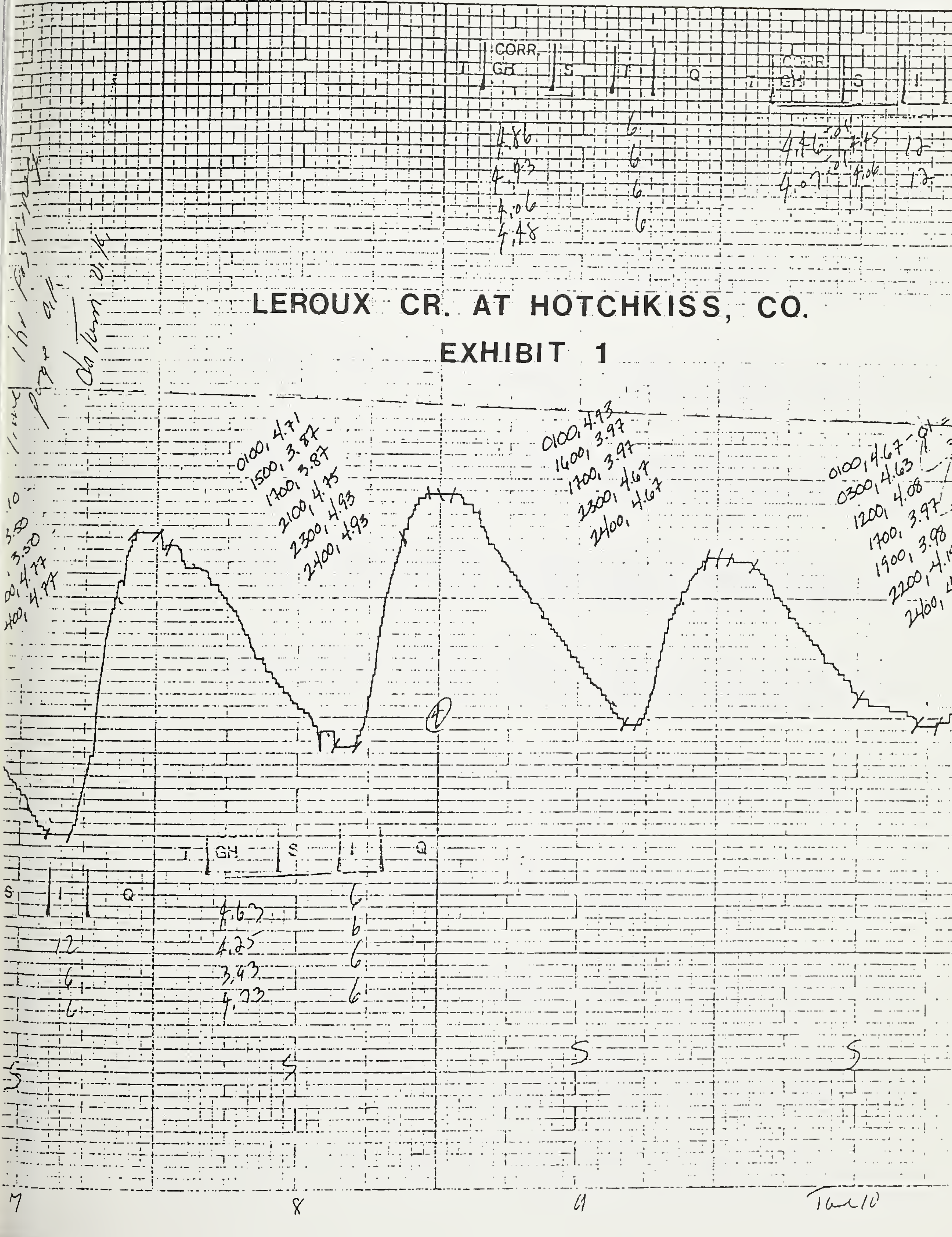
ESTIMATING TOTAL SUSPENDED SEDIMENT YIELD WITH PROBABILITY SAMPLING; Water Resources Research, Vol. 21, No. 9, pp. 1381-1388; 1985.

MEASURING SUSPENDED SEDIMENT IN SMALL MOUNTAIN STREAMS; USDA Forest Service General Technical Report PSW-83; pp. 1-9; 1985.

... CHART FOR STEVENS RECORDERS—MFD. BY LEUPOLD & STEVENS, INC., P.O. BOX 688, BEAVERTON, OREGON 97075, U.S.A.

LEROUX CR. AT HOTCHKISS, CO.

EXHIBIT 1



UNITED STATES DEPARTMENT OF INTERIOR - GEOLOGICAL SURVEY - WATER RESOURCES DIVISION

EXHIBIT 1-A

EXPANDED RATING TABLE PROCESS DATE: 12-MAR-85 07:22 GBO RATING NO 4.0

09135900 LEROUX CREEK AT HOTCHKISS, CO. TYPE LINEAR

BASED ON .... DISCHARGE MEASUREMENTS, NOS ...., AND ...., AND IS ...... WELL DEFINED BETWEEN ...... AND ...... CFS

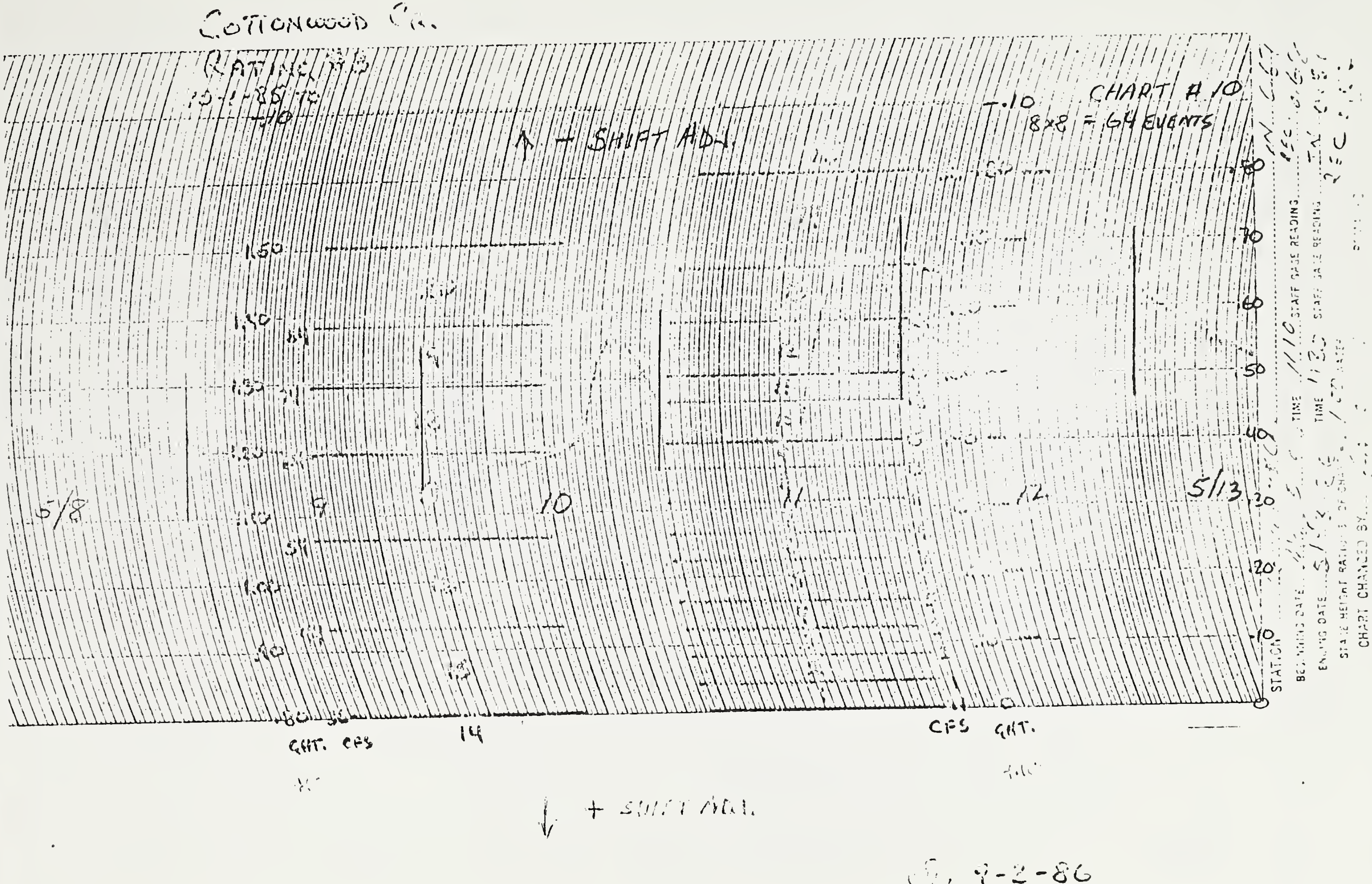
COMP BY ..... DATE ....

RATING TO BE USED STARTING AT: 05/16/8~~5~~4 (0100)

CKD. BY ..... DATE ....

GAGE HEIGHT (FEET)	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	DIFF IN G PER TENTH GH
	DISCHARGE IN CUBIC FEET PER SECOND						(EXPANDED PRECISION)				
2.50	1.70*	1.87	2.04	2.21	2.38	2.55	2.72	2.89	3.06	3.23	1.70
2.60	3.40*	3.68	3.96	4.24	4.52	4.80	5.08	5.36	5.64	5.92	2.80
2.70	6.20*	6.63	7.06	7.49	7.92	8.35	8.78	9.21	9.64	10.1	4.3
2.80	10.5*	11.0	11.6	12.1	12.6	13.2	13.7	14.2	14.7	15.3	5.3
2.90	15.8*	16.4	17.0	17.7	18.3	18.9	19.5	20.1	20.8	21.4	6.2
3.00	22.0*	22.7	23.4	24.1	24.8	25.5	26.2	26.9	27.6	28.3	7.0
3.10	29.0*	29.9	30.7	31.6	32.4	33.3	34.1	35.0	35.8	36.7	8.5
3.20	37.5	38.4	39.2	40.1	40.9	41.8	42.6	43.5	44.3	45.2	8.5
3.30	46.0*	46.9	47.8	48.7	49.6	50.5	51.4	52.3	53.2	54.1	9.0
3.40	55.0	55.9	56.8	57.7	58.6	59.5	60.4	61.3	62.2	63.1	9.0
3.50	64.0*	65.0	66.0	67.0	68.0	69.0	70.0	71.0	72.0	73.0	10.0
3.60	74.0	75.0	76.0	77.0	78.0	79.0	80.0	81.0	82.0	83.0	10.0
3.70	84.0	85.0	86.0	87.0	88.0	89.0	90.0	91.0	92.0	93.0	10.0
3.80	94.0*	95.2	96.4	97.6	98.8	100.0	101.2	102.4	103.6	104.8	12.0
3.90	106.0	107.2	108.4	109.6	110.8	112.0	113.2	114.4	115.6	116.8	12.0
4.00	118.0	119.2	120.4	121.6	122.8	124.0	125.2	126.4	127.6	128.8	12.0
4.10	130.0*	131.3	132.6	133.9	135.2	136.5	137.8	139.1	140.4	141.7	13.0
4.20	143.0	144.3	145.6	146.9	148.2	149.5	150.8	152.1	153.4	154.7	13.0
4.30	156.0	157.3	158.6	159.9	161.2	162.5	163.8	165.1	166.4	167.7	13.0
4.40	169.0	170.3	171.6	172.9	174.2	175.5	176.8	178.1	179.4	180.7	13.0
4.50	182.0*	183.5	185.0	186.5	188.0	189.5	191.0	192.5	194.0	195.5	15.0
4.60	197.0	198.5	200.0	201.5	203.0	204.5	206.0	207.5	209.0	210.5	15.0
4.70	212.0*	213.6	215.2	216.8	218.4	220.0	221.6	223.2	224.8	226.4	16.0
4.80	228.0	229.6	231.2	232.8	234.4	236.0	237.6	239.2	240.8	242.4	16.0
4.90	244.0	245.6	247.2	248.8	250.4	252.0	253.6	255.2	256.8	258.4	16.0
5.00	260.0	261.6	263.2	264.8	266.4	268.0	269.6	271.2	272.8	274.4	16.0
5.10	276.0	277.6	279.2	280.8	282.4	284.0	285.6	287.2	288.8	290.4	16.0
5.20	292.0	293.6	295.2	296.8	298.4	300.0	301.6	303.2	304.8	306.4	16.0
5.30	308.0	309.6	311.2	312.8	314.4	316.0	317.6	319.2	320.8	322.4	16.0
5.40	324.0	325.6	327.2	328.8	330.4	332.0	333.6	335.2	336.8	338.4	16.0
5.50	340.0*	341.8	343.6	345.4	347.2	349.0	350.8	352.6	354.4	356.2	18.0
5.60	358.0	359.8	361.6	363.4	365.2	367.0	368.8	370.6	372.4	374.2	18.0
5.70	376.0	377.8	379.6	381.4	383.2	385.0	386.8	388.6	390.4	392.2	18.0
5.80	394.0	395.8	397.6	399.4	401.2	403.0	404.8	406.6	408.4	410.2	18.0
5.90	412.0	413.8	415.6	417.4	419.2	421.0	422.8	424.6	426.4	428.2	18.0
6.00	430.0*	431.9	433.8	435.7	437.6	439.5	441.4	443.3	445.2	447.1	19.0
6.10	449.0	450.9	452.8	454.7	456.6	458.5	460.4	462.3	464.2	466.1	19.0
6.20	468.0	469.9	471.8	473.7	475.6	477.5	479.4	481.3	483.2	485.1	19.0
6.30	487.0	488.9	490.8	492.7	494.6	496.5	498.4	500.3	502.2	504.1	19.0

EXHIBIT 2



Cottonwood Cr.
Rating #3
10-1-85 to
CHART # 10
8×8 = 64 EVENTS
↑ − SHIFT ADJ.
5/8
10
11
12
5/13
1.50
1.40
1.30
1.20
1.10
1.00
.90
.80
80
70
60
50
40
30
20
10
STATION
BEGINNING DATE
ENDING DATE
STAGE HEIGHT RATIO
CHART CHANGED BY
TIME
STAFF GAGE READING
GHT. CFS
14
CFS GHT.
↓ + SHIFT ADJ.
9-2-86

RATING # 1

9–210–4
(Rev. 5–62)

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY (WATER RESOURCES DIVISION)

Rating table for COTTONWOOD CREEK NEAR PIÑON, COLO. Dated JUNE 17, 1985 Sta. No.

from OCT. 29, 1984 to JUNE 4, 1985; from to

from to ; from to

Gage height	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	Difference
Feet	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs
0.0											
.1	0	.11	.22	.33	.44	.55	.66	.77	.88	.99	
.2	1.10	1.26	1.42	1.58	1.74	1.90	2.06	2.22	2.38	2.54	1.1
.3	2.70	2.93	3.16	3.39	3.62	3.85	4.08	4.31	4.54	4.77	1.6
.4	5.00	5.35	5.70	6.05	6.40	6.75	7.10	7.45	7.80	8.15	2.3
.5	8.50	8.90	9.30	9.70	10.1	10.5	10.9	11.3	11.7	12.1	3.5
.6	12.5	13.0	13.6	14.2	14.7	15.2	15.8	16.4	16.9	17.4	4.0
.7	18.0	18.6	19.3	20.0	20.6	21.2	21.9	22.6	23.2	23.8	5.5
.8	24.5	25.2	25.9	26.6	27.3	28.0	28.7	29.4	30.1	30.8	6.5
.9	31.5	32.4	33.2	34.0	34.9	35.8	36.6	37.4	38.3	39.2	7.0
1.0	40.0	40.9	41.8	42.7	43.6	44.5	45.4	46.3	47.2	48.1	8.5
.1	49.0	50.0	51.0	52.0	53.0	54.0	55.0	56.0	57.0	58.0	9.0
.2	59.0	60.1	61.2	62.3	63.4	64.5	65.6	66.7	67.8	68.9	10
.3	70.0										11
.4	84.0										14
.5	100										16
.6											
.7											
.8											
.9											
2.0											
.1											
.2											
.3											
.4											
.5											
.6											
.7											
.8											
.9											

EXHIBIT 2-A1

Computed by [signature] 6/17/1985 Checked by / / 19 Remarks

☆ U.S. GOVERNMENT PRINTING OFFICE : 1981—O—349-325

9–210–a
(Rev. 5–62)

RATING #2

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY (WATER RESOURCES DIVISION)

Rating table for COTTONWOOD CREEK NEAR PIÑON, COLO. Sta. No. .... Dated JUNE 17, 1985

from JUNE 4, 1985 to SEPT. 30, 1985; from .... to ....

from .... to ....; from .... to ....

Gage height	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	Difference
Feet	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs
0.0	0	0.13	0.26	0.39	0.52	0.65	0.78	0.91	1.04	1.17	1.3
.1	1.30	1.47	1.64	1.81	1.98	2.15	2.32	2.49	2.66	2.83	1.7
.2	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25	2.5
.3	5.50	5.85	6.20	6.55	6.90	7.25	7.60	7.95	8.30	8.65	3.5
.4	9.00	9.50	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	5.0
.5	14.0	14.6	15.3	16.0	16.6	17.2	17.9	18.6	19.2	19.8	6.5
.6	20.5	21.2	22.0	22.8	23.5	24.2	25.0	25.8	26.5	27.2	7.5
.7	28.0	29.3	30.6	31.9	33.2	34.5	35.8	37.1	38.4	39.7	13
.8	41.0	42.7	44.4	46.1	47.8	49.5	51.2	52.9	54.6	56.3	17
.9	58.0	60.2	62.4	64.6	66.8	69.0	71.2	73.4	75.6	77.8	22
1.0	80.0	83.5	87.0	90.5	94.0	97.5	101	104	108	112	35
.1	115										
.2											
.3											
.4											
.5											
.6											
.7											
.8											
.9											
2.0											
.1											
.2											
.3											
.4											
.5											
.6											
.7											
.8											
.9											

EXHIBIT 2-A2

Computed by [illegible] 6/17/1985 Checked by .... / ... / 19... Remarks ....

9-210-a
(Rev. 5-62)

UNITED STATES DEPARTMENT OF THE INTERIOR RATING #3

GEOLOGICAL SURVEY (WATER RESOURCES DIVISION)

Rating table for COTTONWOOD CREEK NEAR PIÑON, COLO. Sta. No. ....

Dated AUG. 28, 1986

from OCT. 1, 1985 to SEP. 30, 1986; from .... to ....

from .... to ....; from .... to ....

Gage height	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	Difference
Feet	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs
0.0	0	0.26	0.52	0.78	1.04	1.30	1.56	1.82	2.08	2.34	2.6
.1	2.60	2.97	3.34	3.71	4.08	4.45	4.82	5.19	5.56	5.93	3.7
.2	6.30	6.72	7.14	7.56	7.98	8.40	8.82	9.24	9.66	10.1	4.2
.3	10.5	11.0	11.4	11.8	12.3	12.8	13.2	13.6	14.1	14.6	4.5
.4	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	5.0
.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	|
.6	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	5.0
.7	30.0	30.6	31.2	31.8	32.4	33.0	33.6	34.2	34.8	35.4	6.0
.8	36.0	36.6	37.2	37.8	38.4	39.0	39.6	40.2	40.8	41.4	6.0
.9	42.0	42.7	43.4	44.1	44.8	45.5	46.2	46.9	47.6	48.3	7.0
1.0	49.0	49.8	50.6	51.4	52.2	53.0	53.8	54.6	55.4	56.2	8.0
.1	57.0	57.8	58.6	59.4	60.2	61.0	61.8	62.6	63.4	64.2	8.0
.2	65.0	66.0	67.0	68.0	69.0	70.0	71.0	72.0	73.0	74.0	10
.3	75.0	76.1	77.2	78.3	79.4	80.5	81.6	82.7	83.8	84.9	11
.4	86.0	87.4	88.8	90.2	91.6	93.0	94.4	95.8	97.2	98.6	14
.5	100										
.6											
.7											
.8											
.9											
2.0											
.1											
.2											
.3											
.4											
.5											
.6											
.7											
.8											
.9											

EXHIBIT 2-A3

Computed by .... 8/28/1986. Checked by .... / ..... / 19..... Remarks ....

☆ U.S. GOVERNMENT PRINTING OFFICE : 1981—O-343-325

9-210-a
(Rev. 5-62)

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY (WATER RESOURCES DIVISION)

RATING #4

Rating table for COTTONWOOD CREEK NEAR PIÑON, COLO. Sta. No. .... Dated OCT. 26, 1987

from OCT. 1, 1986 to ....; from .... to ....

from .... to ....; from .... to ....

Gage height	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09	Difference
Feet	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs	Cfs
0.0	0.00	0.12	0.24	0.36	0.48	0.60	0.72	0.84	0.96	1.08	1.2
.1	1.20	1.39	1.58	1.77	1.96	2.15	2.34	2.53	2.72	2.91	1.9
.2	3.10	3.37	3.64	3.91	4.18	4.45	4.72	4.99	5.26	5.53	2.7
.3	5.80	6.18	6.56	6.94	7.32	7.70	8.08	8.46	8.84	9.22	3.8
.4	9.60	10.1	10.6	11.1	11.6	12.0	12.5	13.0	13.5	14.0	4.9
.5	14.5	15.2	15.8	16.4	17.1	17.8	18.4	19.0	19.7	20.4	6.5
.6	21.0	21.7	22.4	23.1	23.8	24.5	25.2	25.9	26.6	27.3	7.0
.7	28.0	29.0	29.9	30.8	31.8	32.8	33.7	34.6	35.6	36.6	9.5
.8	37.5	38.8	40.0	41.2	42.5	43.8	45.0	46.2	47.5	48.8	12.5
.9	50.0	51.3	52.6	53.9	55.2	56.5	57.8	59.1	60.4	61.7	13
1.0	63.0	64.3	65.6	66.9	68.2	69.5	70.8	72.1	73.4	74.7	13
.1	76.0										
.2											
.3											
.4											
.5											
.6											
.7											
.8											
.9											
2.0											
.1											
.2											
.3											
.4											
.5											
.6											
.7											
.8											
.9											

EXHIBIT 2-A4

Computed by .... 10/26/1987 Checked by .... / ... / 19... Remarks ....

☆ U.S. GOVERNMENT PRINTING OFFICE : 1981—O—349-325

USDA-FOREST SERVICE

COMPUTATION SHEET

SHEET 1 OF 1

Subject: LEROUX CREEK – FLOW DURATION ANALYSIS

MADE BY SMIRNOW

CHECKED BY 9-9-86 (Initial and date)

3HR EVENT INCREMENTS

FLOW CATEGORY

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Σ+
JUNE 4																					8
5																					8
6																					8
7																					8
8																					8
9																					8
10																					8

EVENTS BY CATEGORY Σ+ 2 11 8 12 8 3 4 6 2 = 56✓ — 56 TOTAL EVENTS

% Σ+ 4 20 14 21 14 5 7 11 4 = 100✓

% FLOW > CATEGORY MINIMUM 100 96 76 62 41 27 22 15 4 0

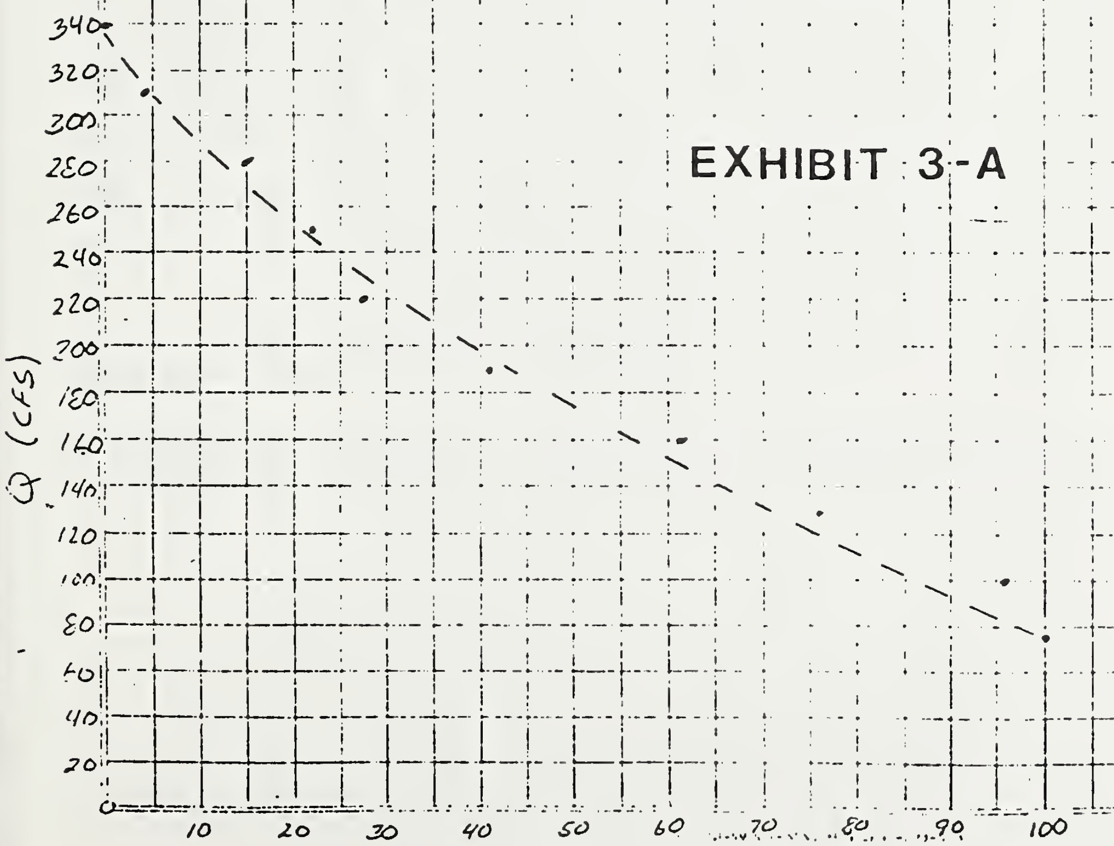


EXHIBIT 3-A

00-71 (7-68)

FLOW DURATION ANALYSIS

COMPOSITE
1985, 1986, 1987 WY

USDA-FOREST SERVICE

SHEET 1 OF 4

COMPUTATION SHEET

MADE BY SMIRNOW

Subject: LOCATION: COTTONWOOD CREEK - RATING #1-4

CHECKED BY

do.

EVENT TALLY

CAT.	RANGE (CFS)	$\bar{X}$ (CFS)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Σ_i	EXC. CFS	%
1	.1-1	.5																5370	100	61.3
2	1-2	1.5																829	38.7	9.5
3	2-3	2.5																462	29.2	5.3
4	3-5	4																311	23.9	3.5
5	5-7	6																248	20.4	2.8
6	7-9	8																183	17.6	2.1
7	9-11	10																120	15.5	1.4
8	11-13	12																208	14.1	2.4
9	13-15	14																174	11.7	2.0
10	15-18	16.5																206	9.7	2.3
11	18-20	19																76	7.4	0.9
12	20-24	22																215	6.5	2.4
13	24-28	26																139	4.1	1.6
14	28-36	32																154	2.5	1.8
15	36-44	40																41	0.7	0.5
16	44-54	49																15	0.2	0.2
17	54-64	59																6	0	0.1
18	64-74	69																3	0	0.03
19	74-84	79																8760	0	100.1
20	84-100	92																		

EXHIBIT 3-1

EVENT DURATION = 3.0 HRS

REMARKS: TOTAL EVENTS: 2920 / YEAR × 3 =
8760

1985

FLOW DURATION ANALYSIS — WATER YEAR

USDA-FOREST SERVICE

SHEET 2 OF 4

MADE BY SMIRNOW

CHECKED BY

COMPUTATION SHEET

Subject: LOCATION: COTTONWOOD CREEK - RATING #1,2

CAT.	RANGE (CFS)	$\bar{X}$ (CFS)	EVENT TALLY (1–15)	Σ_i	% EXC. CFS	%
1	.1-1	.5	PLUS 844 + 1280 = 2128 EVENTS	2128	100	72.9
2	1-2	1.5		30	27.1	1.0
3	2-3	2.5		98	26.1	3.3
4	3-5	4		141	22.8	4.8
5	5-7	6		89	18.0	3.0
6	7-9	8		64	15.0	2.2
7	9-11	10		29	12.8	1.0
8	11-13	12		75	11.8	2.6
9	13-15	14		31	9.2	1.1
10	15-18	16.5		91	8.1	3.1
11	18-20	19		18	5.0	0.6
12	20-24	22		53	4.4	1.8
13	24-28	26		5	2.6	0.2
14	28-36	32		25	2.4	0.9
15	36-44	40		31	1.5	1.1
16	44-54	49		11	0.4	0.4
17	54-64	59		1	0	0.03
18	64-74	69		2920	0	100
19	74-84	79				
20	84-100	92				

EXHIBIT 3-2

EVENT DURATION = 3.0 HRS

REMARKS: RATING #1 IN EFFECT 10-1-85 TO 6-3-85
RATING #2 IN EFFECT 6-4-85 THROUGH 9-30-85

GHT RECORD BEGAN 3-10-85; NO GHT RECORD PRIOR.

Q OF < 1 CFS ASSUMED FROM 10-1-84 THROUGH 3-9-85.

TOTAL EVENTS = 365 X 8 = 2920 / YEAR.

FLOW DURATION ANALYSIS — WATER YEAR

USDA-FOREST SERVICE

SHEET 3 OF 4

COMPUTATION SHEET

MADE BY SMIRNOW

LOCATION: COTTONWOOD CREEK - RATING # 3

Subject:

CHECKED BY

Initials / Date

CAT.	RANGE (CFS)	$\bar{X}$ (CFS)	EVENT TALLY 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	Σ_i	% ≥ CFS	%
1	.1-1	.5	PLUS 1827 ADD'L EVENTS	1917	100	65.7
2	1-2	1.5		77	34.3	2.6
3	2-3	2.5		64	31.7	2.2
4	3-5	4		89	29.5	3.0
5	5-7	6		87	26.5	3.0
6	7-9	8		56	23.5	1.9
7	9-11	10		50	21.6	1.7
8	11-13	12		123	19.9	4.2
9	13-15	14		130	15.7	4.5
10	15-18	16.5		82	11.2	2.8
11	18-20	19		36	8.4	1.2
12	20-24	22		98	7.2	3.4
13	24-28	26		69	3.8	2.4
14	28-36	32		42	1.4	1.4
15	36-44	40		2920	0	100.0
16	44-54	49				
17	54-64	59				
18	64-74	69				
19	74-84	79				
20	84-100	92				

EXHIBIT 3-3

EVENT DURATION = 3.0 HRS

REMARKS: RATING #3 IN EFFECT 10-1-85 THROUGH 9-30-8[illegible]

Q OF < 1 CFS ASSUMED FOR PERIODS OF NO GHT RECORD & ICE AFFECTED PERIODS.

FLOW DURATION ANALYSIS

1981 WATER YEAR

USDA-FOREST SERVICE

COMPUTATION SHEET

LOCATION: COTTONWOOD CREEK - RATING # 4

SHEET 4 OF 4

MADE BY SMIRNOW

CHECKED BY

CAT.	RANGE (CFS)	$\bar{X}$ (CFS)	EVENT TALLY (1–15)	Σ_i	% ΣTC CFS	%
1	.1-1	.5	48 248 224 PLUS 751	1325	100	45.4
2	1-2	1.5	32 10 32 10 24 224 200 96	722	54.6	24.7
3	2-3	2.5	32 128 32 40	300	29.9	10.3
4	3-5	4	24	81	19.6	2.8
5	5-7	6		72	16.8	2.5
6	7-9	8		63	14.3	2.2
7	9-11	10		41	12.1	1.4
8	11-13	12		10	10.7	0.3
9	13-15	14		13	10.4	0.4
10	15-18	16.5		33	10.0	1.1
11	18-20	19		22	8.9	0.8
12	20-24	22		64	8.1	2.2
13	24-28	26		65	5.9	2.2
14	28-36	32		87	3.7	3.0
15	36-44	40		10	0.7	0.3
16	44-54	49		4	0.4	0.1
17	54-64	59		5	0.3	0.2
18	64-74	69		3	0.1	0.1
19	74-84	79				
20	84-100	92				
				2920	0	100

EXHIBIT 3-4

EVENT DURATION = 3.0 HRS

REMARKS: RATING #4 IN EFFECT FROM 10-1-86 TO 9-30-87, WHEN STATION WAS DISMANTLED.

STATION NAME: COTTONWOOD CREEK NEAR PINON, COLORADO

Q(cfs)	TSS(mg/l)
0.2	23
2.2	15
11.9	15
11.9	14
9.9	8
9.9	6
20.1	38
20.1	37
16.4	60
16.4	61
27.8	101
27.8	99
17.2	28
17.2	29
19.9	32
19.9	29
23.0	24
23.0	27
20.9	60
20.9	64
12.4	45
12.4	47
1.5	31
0.9	20
0.9	16
3.4	8
3.4	10
12.9	42
12.9	41
16.2	60
16.2	61
31.2	130
31.2	126
31.5	99
31.5	96
20.8	110
20.8	108
17.8	101
17.8	108
6.4	24
6.4	26
1.2	28
1.2	27
0.2	5
0.2	4

Q(cfs)	BEDLOAD CATCH (g)
31.5	1201.0
26.6	204.0
28.0	128.2
11.3	27.3
11.9	3.0
20.1	83.5
16.4	466.2
27.8	142.9
17.2	8.9
19.9	9.2
23.0	17.4
12.9	28.7
31.2	194.1
31.5	128.2
20.8	96.4

SEDIMENT RATING EQUATIONS (DOUBLE POWER CURVES): TSS = 2.45Q^1 + .03118Q^2
BEDLOAD = 23.4Q^.5 + .00008Q^4
(EQUATIONS DERIVED ON HP-85 CURVE FITTING PROGRAM)

EXHIBIT 4

STATION NAME: COTTONWOOD CREEK NEAR PINON, COLO.
WATER YEAR: 1985, 1986, 1987
EQUATION: TSS = aQ^b + cQ^d where: a=2.45 b=1
(DOUBLE POWER CURVE) c=0.03118 d=2
EVENT DURATION (HOURS) = 3
TSS RATING EQUATION DERIVED FROM HP-85 CURVE FITTING PROGRAM
YIELD = (cfs)(mg/l)(.0027)*(# events/8)

1985	FLOW CAT. (CFS)	mg/l @ EVENT Q	NO. OF EVENTS	YIELD (TONS)
	0.5	1.2	2128	0.44
	1.5	3.7	30	0.06
	2.5	6.3	141	0.75
	6.0	15.8	89	2.85
	8.0	21.6	64	3.73
	10.0	27.6	29	2.70
	12.0	33.9	75	10.29
	14.0	40.4	31	5.92
	16.5	48.9	91	24.79
	19.0	57.8	18	6.67
	22.0	69.0	53	27.15
	26.0	84.8	5	3.72
	32.0	110.3	25	29.79
	40.0	147.9	31	61.89
	49.0	194.9	11	35.46
	59.0	253.1	1	5.04

YIELD (TONS/YEAR) = 221.26

1987	FLOW CAT. (CFS)	mg/l @ EVENT Q	NO. OF EVENTS	YIELD (TONS)
	0.5	1.2	1325	0.28
	1.5	3.7	722	1.37
	2.5	6.3	300	1.60
	6.0	15.8	81	2.60
	8.0	21.6	72	4.20
	10.0	27.6	63	5.87
	12.0	33.9	41	5.63
	14.0	40.4	10	1.91
	16.5	48.9	13	3.54
	19.0	57.8	33	12.23
	22.0	69.0	22	11.27
	26.0	84.8	64	47.61
	32.0	110.3	87	103.66
	40.0	147.9	10	19.96
	49.0	194.9	4	12.89
	59.0	253.1	5	25.20
	69.0	317.5	3	22.18

YIELD (TONS/YEAR) = 282.00

1986	FLOW CAT. (CFS)	mg/l @ EVENT Q	NO. OF EVENTS	YIELD (TONS)
	0.5	1.2	1917	0.40
	1.5	3.7	77	0.15
	2.5	6.3	64	0.34
	6.0	15.8	89	2.85
	8.0	21.6	87	5.07
	10.0	27.6	56	5.22
	12.0	33.9	50	6.86
	14.0	40.4	123	23.49
	16.5	48.9	130	35.41
	19.0	57.8	82	30.40
	22.0	69.0	36	18.44
	26.0	84.8	98	72.90
	32.0	110.3	69	82.22

YIELD (TONS/YEAR) = 283.75

MEAN 1985 1986 1987	FLOW CAT. (CFS)	mg/l @ EVENT Q	NO. OF EVENTS	YIELD (TONS)
	0.5	1.2	5370	1.12
	1.5	3.7	829	1.57
	2.5	6.3	462	2.46
	6.0	15.8	311	9.96
	8.0	21.6	248	14.46
	10.0	27.6	183	17.06
	12.0	33.9	120	16.47
	14.0	40.4	208	39.72
	16.5	48.9	174	47.40
	19.0	57.8	206	76.36
	22.0	69.0	76	38.93
	26.0	84.8	215	159.94
	32.0	110.3	154	183.50
	40.0	147.9	41	81.86
	49.0	194.9	15	48.35
	59.0	253.1	6	30.24
	69.0	317.5	3	22.18

AVG YIELD (TONS/YEAR) = 263.86

EXHIBIT 5-1

STATION NAME: COTTONWOOD CREEK NEAR PINON, COLO.
WATER YEAR: 1985, 1986, 1987
EQUATION: BEDLOAD= aQ^b + cQ^d where: a=23.4 b=0.5
(DOUBLE POWER CURVE) c=0.00008 d=4
EVENT DURATION (HOURS) = 3
BEDLOAD RATING EQUATION DERIVED FROM HP-85 CURVE FITTING PROGRAM
BEDLOAD = g/20 MIN. USING HAND HELD HELLEY-SMITH SAMPLER
YIELD = (catch*9)(# events)/907180

1985	FLOW CAT. (CFS)	g/20 MIN @ CAT. Q	NO. OF EVENTS	YIELD (TONS)
	0.5	16.55	2128	0.35
	1.5	28.66	30	0.01
	2.5	37.00	98	0.04
	4.0	46.82	141	0.07
	6.0	57.42	89	0.05
	8.0	66.51	64	0.04
	10.0	74.80	29	0.02
	12.0	82.72	75	0.06
	14.0	90.63	31	0.03
	16.5	100.98	91	0.09
	19.0	112.42	18	0.02
	22.0	128.50	53	0.07
	26.0	155.88	5	0.01
	32.0	216.26	25	0.05
	40.0	352.79	31	0.11
	49.0	624.98	11	0.07
	59.0	1149.13	1	0.01
		YIELD (TONS/YR)	=	1.09

1986	FLOW CAT. (CFS)	g/20 MIN @ CAT. Q	NO. OF EVENTS	YIELD (TONS)
	0.5	16.55	1917	0.31
	1.5	28.66	77	0.02
	2.5	37.00	64	0.02
	4.0	46.82	89	0.04
	6.0	57.42	87	0.05
	8.0	66.51	56	0.04
	10.0	74.80	50	0.04
	12.0	82.72	123	0.10
	14.0	90.63	130	0.12
	16.5	100.98	82	0.08
	19.0	112.42	36	0.04
	22.0	128.50	98	0.12
	26.0	155.88	69	0.11
	32.0	216.26	25	0.05
		YIELD (TONS/YR)	=	1.15

EXHIBIT 5-2

1987	FLOW CAT. (CFS)	g/20 MIN @ CAT. Q	NO. OF EVENTS	YIELD (TONS)
	0.5	16.55	1325	0.22
	1.5	28.66	722	0.21
	2.5	37.00	300	0.11
	4.0	46.82	81	0.04
	6.0	57.42	72	0.04
	8.0	66.51	63	0.04
	10.0	74.80	41	0.03
	12.0	82.72	10	0.01
	14.0	90.63	13	0.01
	16.5	100.98	33	0.03
	19.0	112.42	22	0.02
	22.0	128.50	64	0.08
	26.0	155.88	65	0.10
	32.0	216.26	87	0.19
	40.0	352.79	10	0.03
	49.0	624.98	4	0.02
	59.0	1149.13	5	0.06
	69.0	2007.74	3	0.06
		YIELD (TONS/YR)	=	1.31

MEAN 1985 1986 1987	FLOW CAT. (CFS)	g/20 MIN @ CAT. Q	NO. OF EVENTS	YIELD (TONS)
	0.5	16.55	5370	0.88
	1.5	28.66	829	0.24
	2.5	37.00	462	0.17
	4.0	46.82	311	0.14
	6.0	57.42	248	0.14
	8.0	66.51	183	0.12
	10.0	74.80	120	0.09
	12.0	82.72	208	0.17
	14.0	90.63	174	0.16
	16.5	100.98	206	0.21
	19.0	112.42	76	0.08
	22.0	128.50	215	0.27
	26.0	155.88	139	0.21
	32.0	216.26	154	0.33
	40.0	352.79	41	0.14
	49.0	624.98	15	0.09
	59.0	1149.13	6	0.07
	69.0	2007.74	3	0.06
		AVG YIELD (TONS/YR)=		1.19

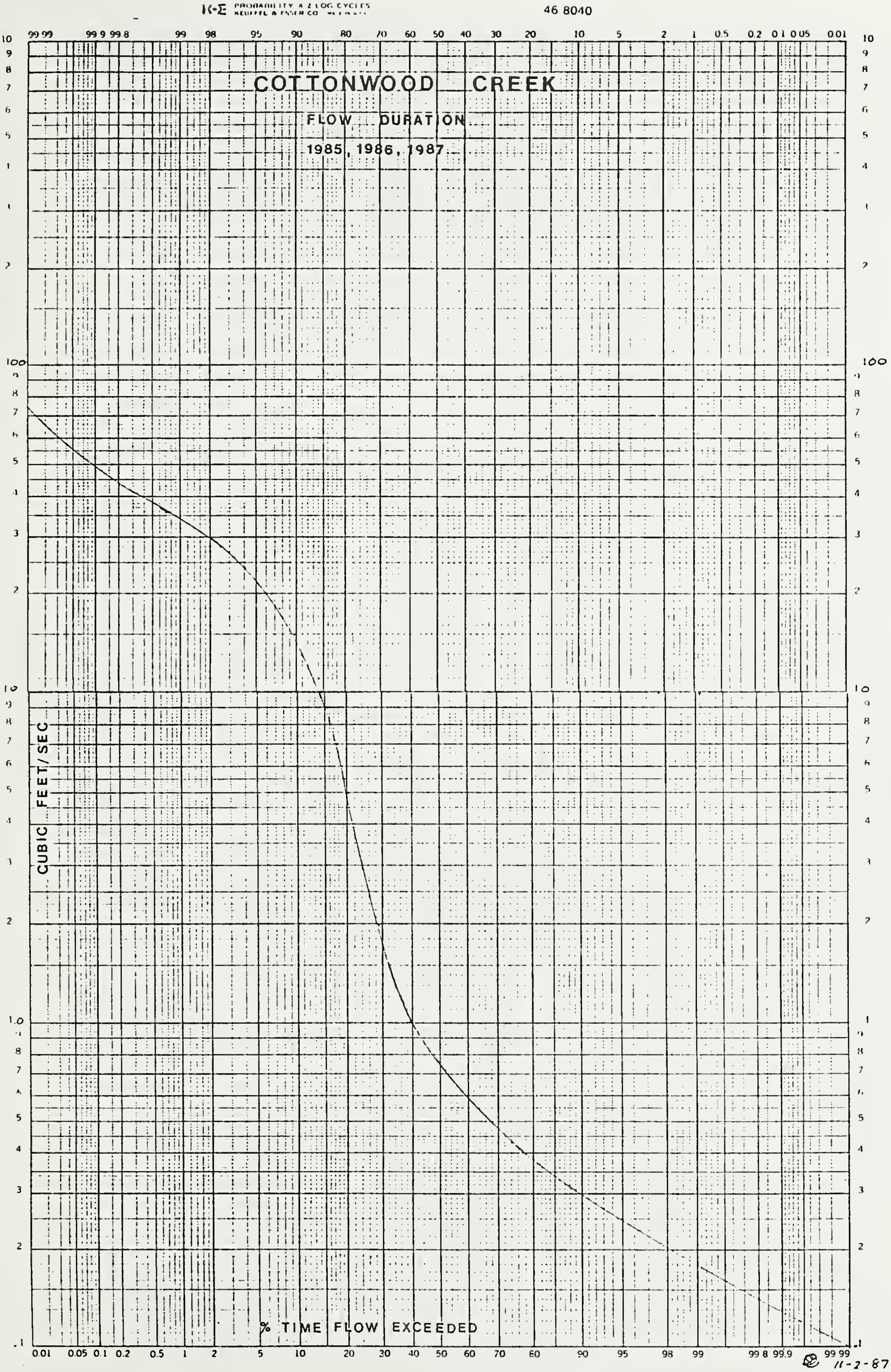
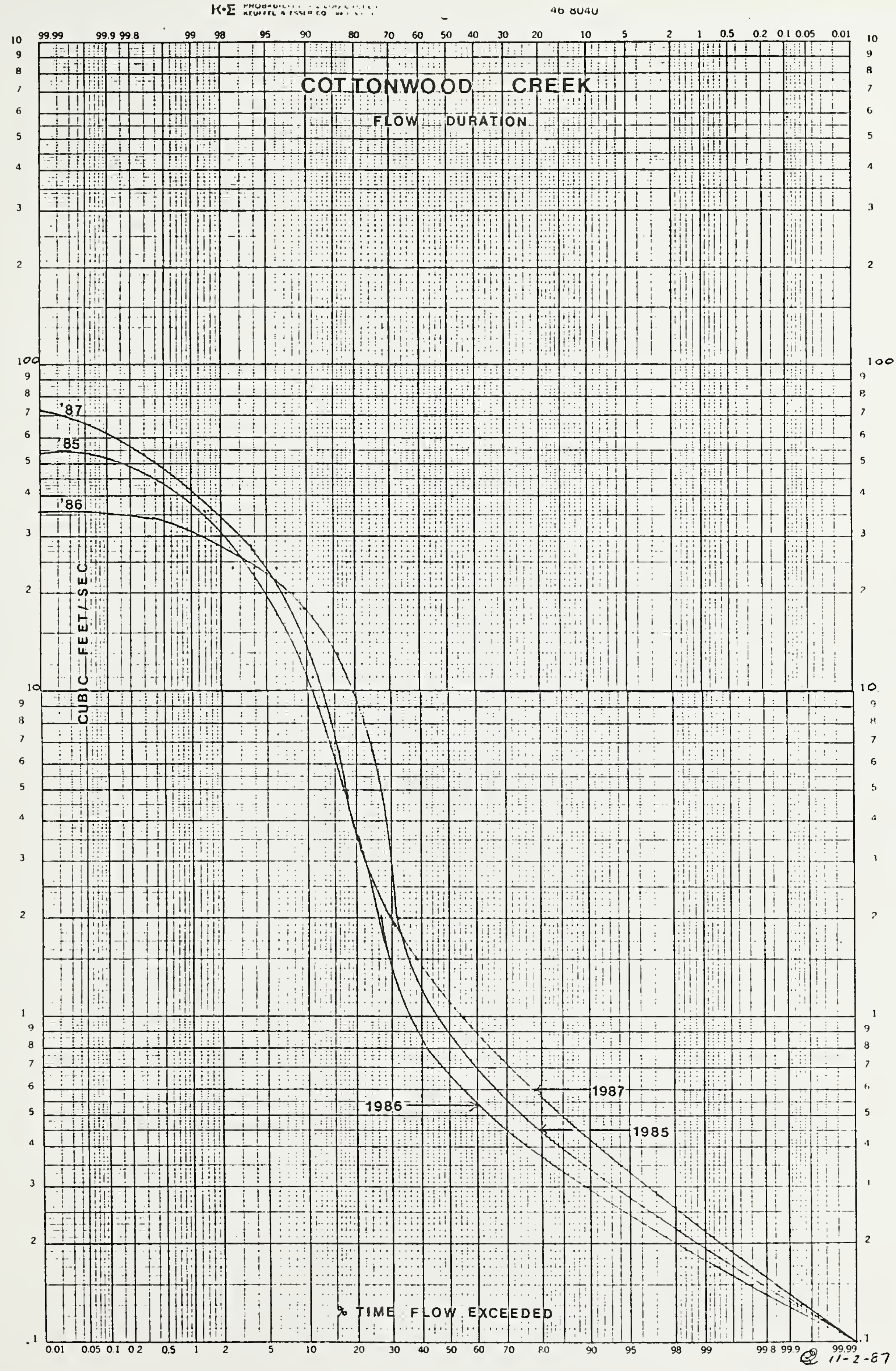

K•E PROBABILITY X 2 LOG CYCLES
46 8040
COTTONWOOD CREEK
FLOW DURATION
1985, 1986, 1987
CUBIC FEET/SEC
% TIME FLOW EXCEEDED
11-2-87

EXHIBIT 6–1



COTTONWOOD CREEK
FLOW DURATION
CUBIC FEET/SEC
% TIME FLOW EXCEEDED
'87
'85
'86
1986
1987
1985
11-2-87

EXHIBIT 6-2

MYLAR/CHART SAMPLES